Enhancing Cost Realism through Risk-Driven Contracting:

Designing Incentive Fees based on Probabilistic Cost Estimates

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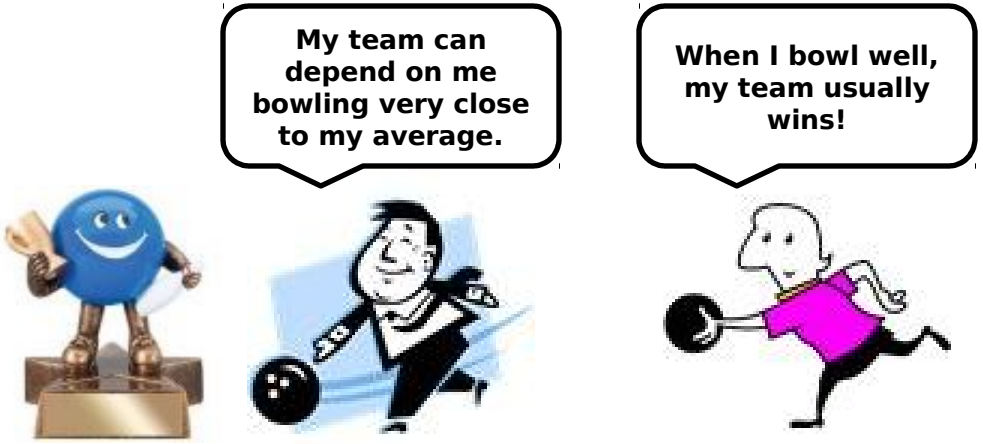
* The views expressed in this presentation are those of the author and do not reflect the official policy or position of the US Government, Department of Defense, or US Air Force

Context
(Part 1)

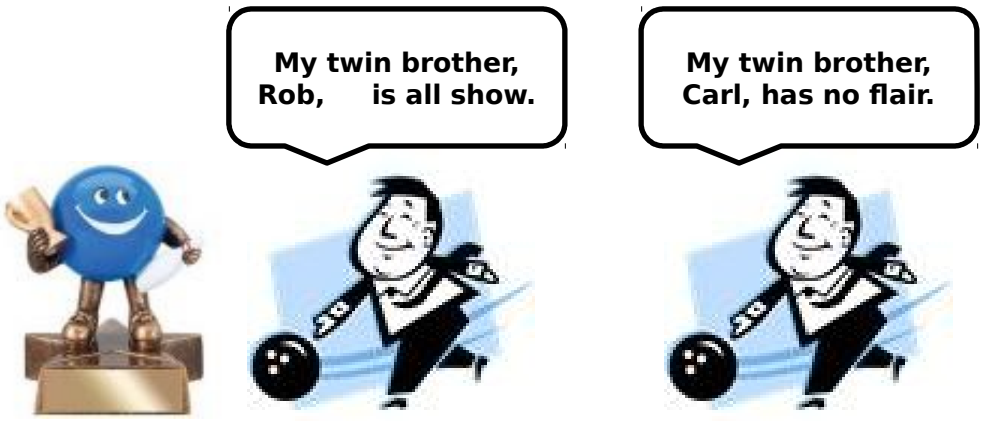


	Consistent Carl	Lucky Lucy
Average	200	100
Standard Deviation*	10	25

- If Carl bowls a 225 and Lucy bowls a 125, who did better?
  - Carl, since it's less likely for him to beat his average by 25 pins

*Bowling handicaps are not calculated this way…most people do not think in the probability domain.

Context (Part 2)



	Consistent Carl	Rowdy Rob
Average	200	200
Standard Deviation*	10	15

- If Carl and Rob both bowl a 210, who did better?
  - Carl, since it's less likely for him to beat his average by 10 pins

Rewards should be based on statistical likelihood, not raw pin count

*Bowling handicaps are not calculated this way…most people do not think in the probability domain.

Bottom Line Up Front

- With long-term production and sustainment contracts at stake, competition to win system development contracts is intense
  - Fixed-price contracts are inappropriate due to their potential for huge losses
  - Cost-plus contracts are normally used, but inadvertently incentivize overly optimistic cost proposals (since there is no chance to incur a loss)
- Risk-driven contracts designed in the probability domain offer a structured method to hold contractors and the government accountable for cost estimates
  - Limit maximum contractor losses to not overly penalize their engagement in risky system development efforts

Risk-driven contracts should reduce cost overruns during EMD when cost uncertainty is high

Outline

- Motivation
- Common Contract Types
- Incentive Fee Design
- Discussion
- Summary

Outline

- Motivation
  - Burning Platform
  - Cost Growth vs. Cost Overruns
  - Overemphasis on Technical Cost Drivers?
  - Optimism Bias
  - Economic Theory
- Common Contract Types
- Incentive Fee Design
- Discussion
- Summary

Motivation
Burning Platform

Analysis of DOD Major Defense Acquisition Program Portfolios (Fiscal Year 2009 Dollars)			
Portfolio status	**Fiscal year 2003 portfolio**	**Fiscal year 2007 portfolio**	**Fiscal year 2008 portfolio**
Number of programs	77	95	96
Total planned commitments	$1.2 trillion	$1.6 trillion	$1.6 trillion
Commitments outstanding	$724 billion	$875 billion	$786 billion
Change to total research and development costs from first estimate	37 percent	40 percent	42 percent
Change in total acquisition cost from first estimate	19 percent	26 percent	25 percent
Estimated total acquisition cost growth	$183 billion	$301 billion	$296 billion
Share of programs with 25 percent or more increase in program acquisition unit cost	41 percent	44 percent	42 percent
Average delay in delivering initial capabilities	18 months	21 months	22 months

Source: GAO analysis of DOD data.

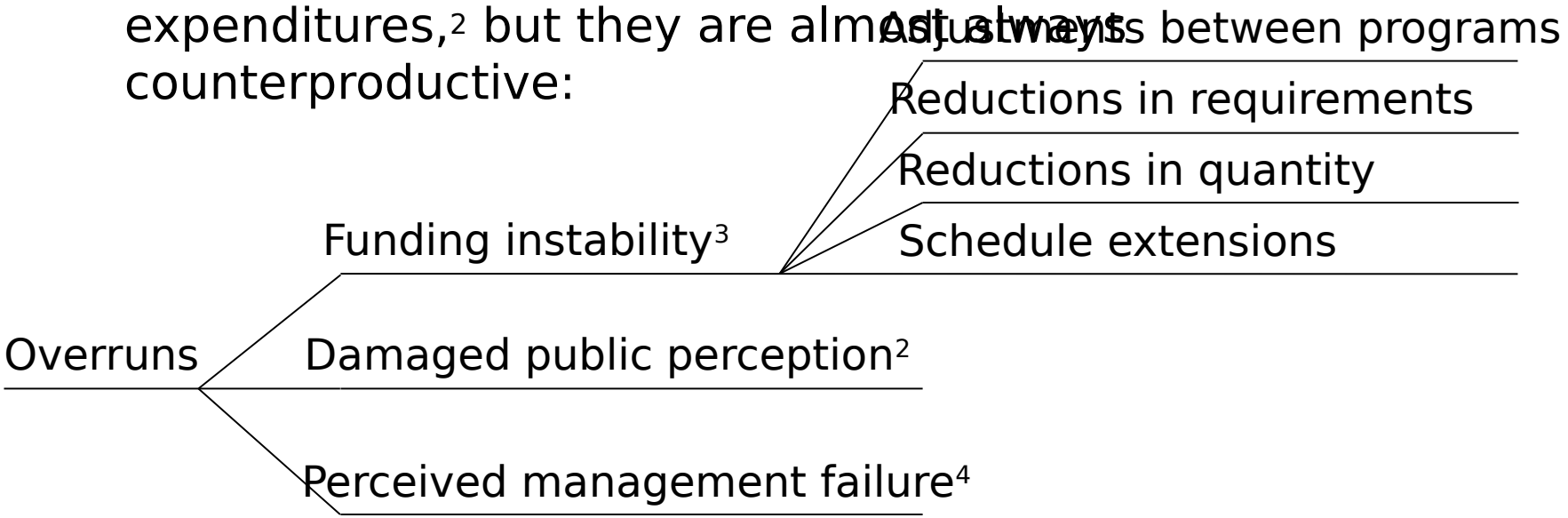
- FY13 President's Budget Request is $614B (including OCO)[1]
  - $179B for acquisitions ($109B for procurement, $70B for RDT&E)

$296B unfunded liability greater than annual acquisitions budget

Table copied from GAO-09-663T, *Defense Acquisitions: Charting a Course for Lasting Reform*, 2009.

Motivation
Cost Growth vs. Cost Overruns

- Cost growth implies increase to system lifecycle costs
- Cost overrun implies exceeding the current contract target cost
  - Overruns do not necessarily indicate excessive expenditures,[2] but they are almost always counterproductive:



Motivation
Overemphasis on Technical Cost Drivers?

- Cost estimation guides written by:
  - Army, Navy, Air Force, NASA, GAO, RAND, ISPA/SCEA, SSCAG
- Articles, conferences, and training opportunities from:
  - ISPA, SCEA, SSCAG, SCAF
- Textbook:
  - Garvey, P. R. (2000). Probability methods for cost uncertainty analysis: A systems engineering perspective. New York, NY: Marcel Dekker.
- Popular software tools:
  - ACEIT, Crystal Ball, @RISK, PRICE, SEER, NAFCOM, COCOMO II, COSYSMO

In an unbiased world, subject matter experts applying these tools and best practices would produce more accurate and reliable cost estimates

International Society of Parametric Analysts (ISPA); Society of Cost Estimating and Analysis (SCEA); Space Systems Cost Analysis Group (SSCAG); Society of Cost Analysis and Forecasting (SCAF); Automated Cost Estimating Integrated Tools (ACEIT); System Evaluation and Estimation of Resources (SEER);
NASA/Air Force Cost Model (NAFCOM); Constructive Cost Model (COCOMO);

Motivation
Optimism Bias

- Optimistic technical estimates
  - Elicitation techniques required to “calibrate” experts confronted with uncertainty[5]
- Optimistic management estimates
  - Government:
    - To maintain the appearance of affordability for new and existing programs, cost estimates that fit within authorized budgets are at least tacitly encouraged by the Services[3,6]
    - US Congressmen sometimes support programs with poor business cases when the funding is allocated to their constituents
  - Contractors:
    - Underestimate competitive program costs when not exposed to the risk of a loss

“I can think of a lot of programs in the Boeing Company where, if the estimate had been realistic, you wouldn’t have had the program. And that is the truth.”[7]

W. M. Allen – President, Boeing –

Motivation
Economic Theory

- Moral Hazard: the propensity to act differently when insulated from the risk of a loss[8]
  - Underestimate competitive cost-plus proposals
  - Carry excess organization slack (operating and investment expenses)[6]
- Adverse Selection: government has imperfect knowledge of the expected costs of each contractor[8]
  - Contractors have superior knowledge of underlying cost factors[6]
    - Direct access to the technicians and engineers who will be working on the contract
    - Close relationships with key suppliers
    - Locally optimized parametric cost models

Overcoming the issues associated with moral hazard and adverse selection requires risk sharing of overruns[8]

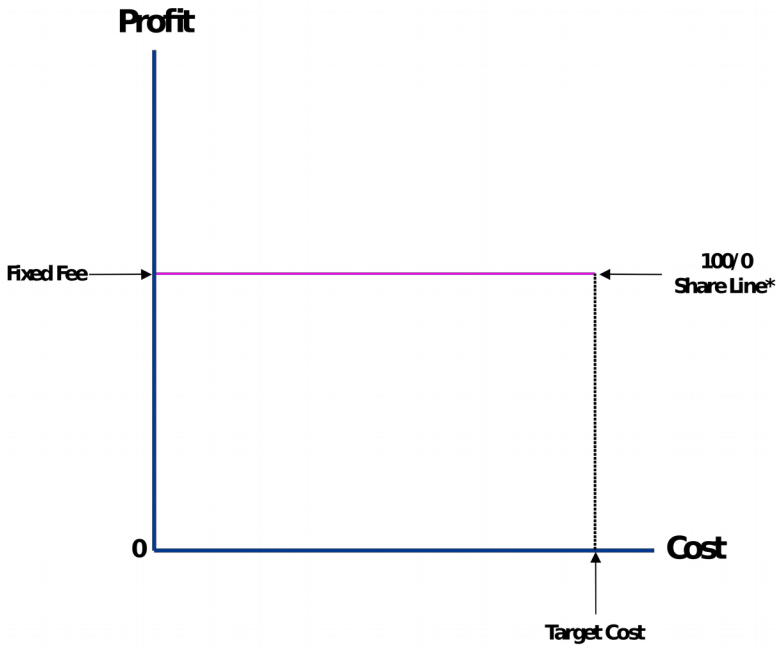
Motivation
Economic Theory

- Contractors still benefit when they receive no profit[9]
  - Scientists and engineers are gainfully employed (or hired) and available for future programs
  - Technology competency is accrued, which improves their market position for future government and commercial business
  - Facilities and equipment are often maintained and upgraded at the government's expense
  - Overhead expenses for other programs (and potential new programs) are slightly reduced by contributions to the overhead pool

Outline

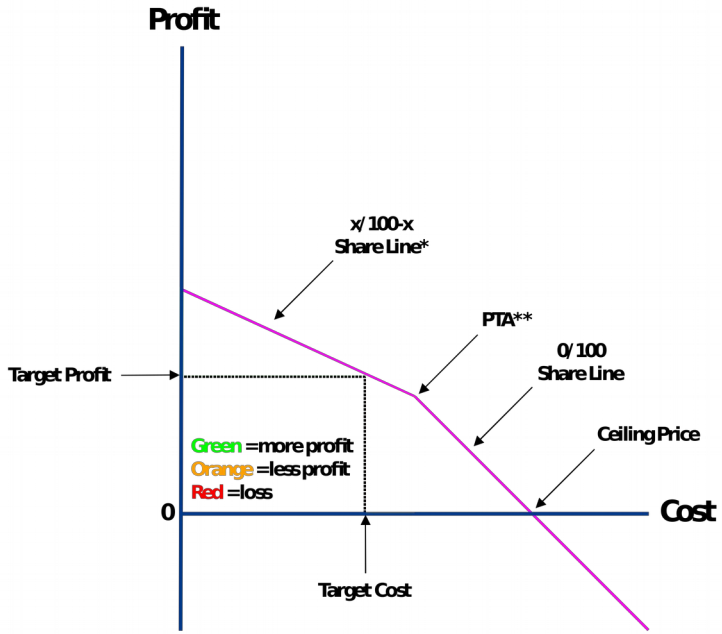
- Motivation
- Common Contract Types
  - Cost Plus Fixed Fee (CPFF)
  - Cost Plus Incentive Fee (CPIF)
  - Fixed Price Incentive Firm Target (FPIF)
  - Firm Fixed Price (FFP)
  - Usage by Acquisition Lifecycle Phase
  - Current Policy
- Incentive Fee Design
- Discussion
- Summary

CPFF



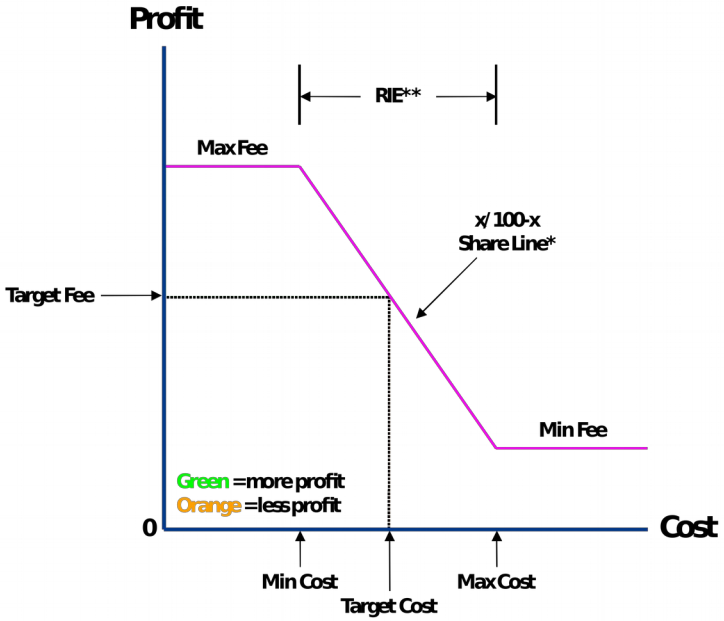
*100 = government's share, 0 = contractor's share

FPIF



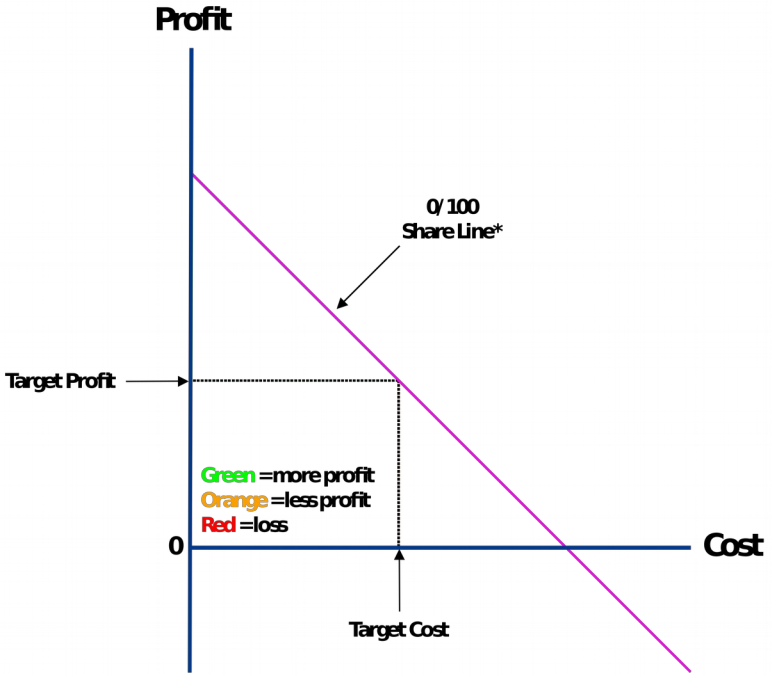
*x = government's share, 100-x = contractor's share
**PTA = Point of Total Assumption: point above which contractor assumes all costs

CPIF



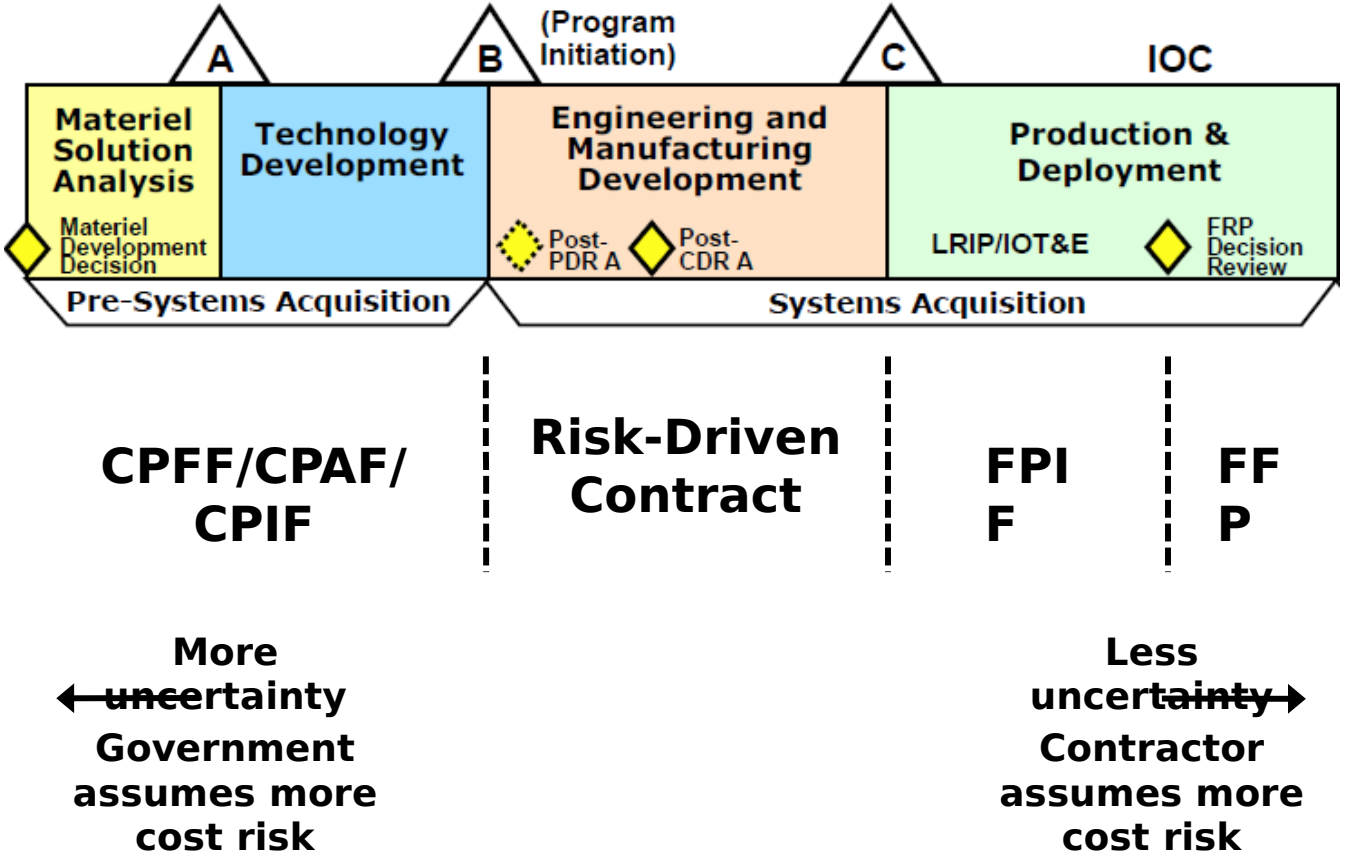
*x = government's share, 100-x = contractor's share
**RIE = Range of Incentive Effectiveness

FFP



*0 = government's share, 100 = contractor's share

Common Contract Types
Usage by Acquisition Lifecycle Phase



New risk-driven contract framework is targeted at EMD phase, but might also be appropriate during Tech Development or LRIP

Figure adapted from DoD Instruction 5000.02, 2008, p. 12.

Common Contract Types
Current Policy

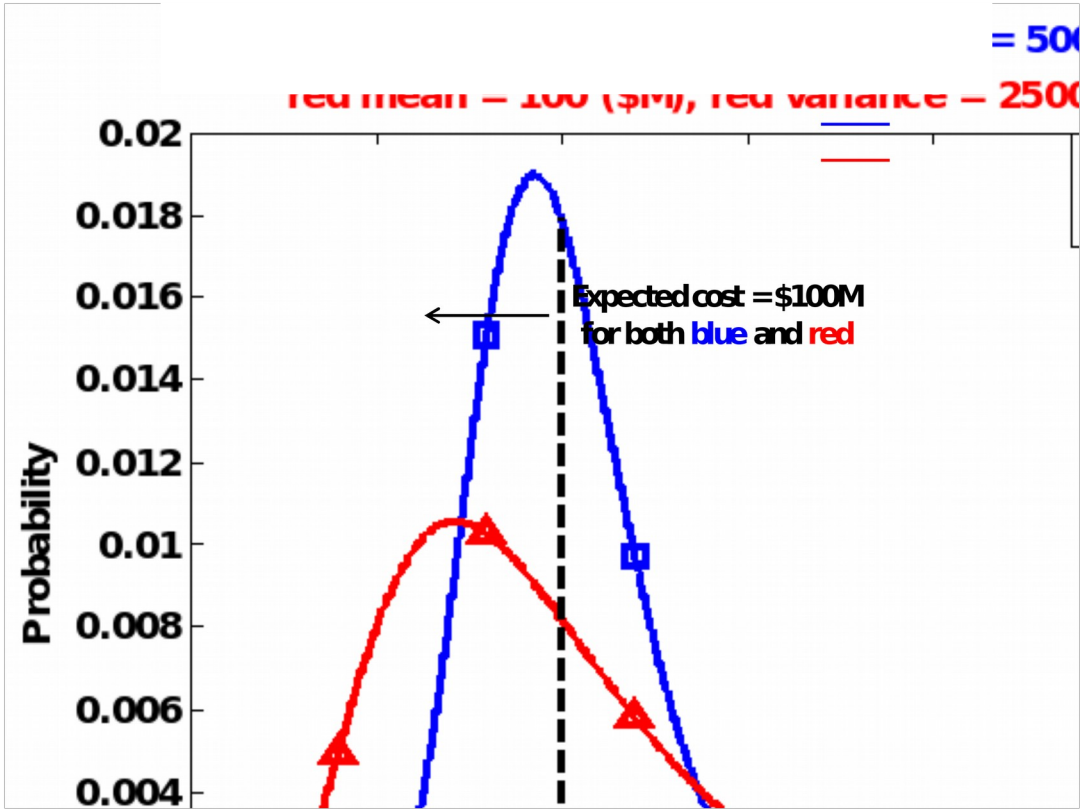
- USD(AT&L) recently set FPIF contract with 50/50 share line and 120% ceiling as the point of departure[10]
  - Normally appropriate for early production
  - Compromise between CPAF and FFP
  - One size does not fit all

Policy does not directly address system development phase when cost uncertainty is even higher

Outline

- Motivation
- Common Contract Types
- Incentive Fee Design
  - Notional Cost Estimates
  - FPIF Method
  - Risk-Driven Method
- Discussion
- Summary

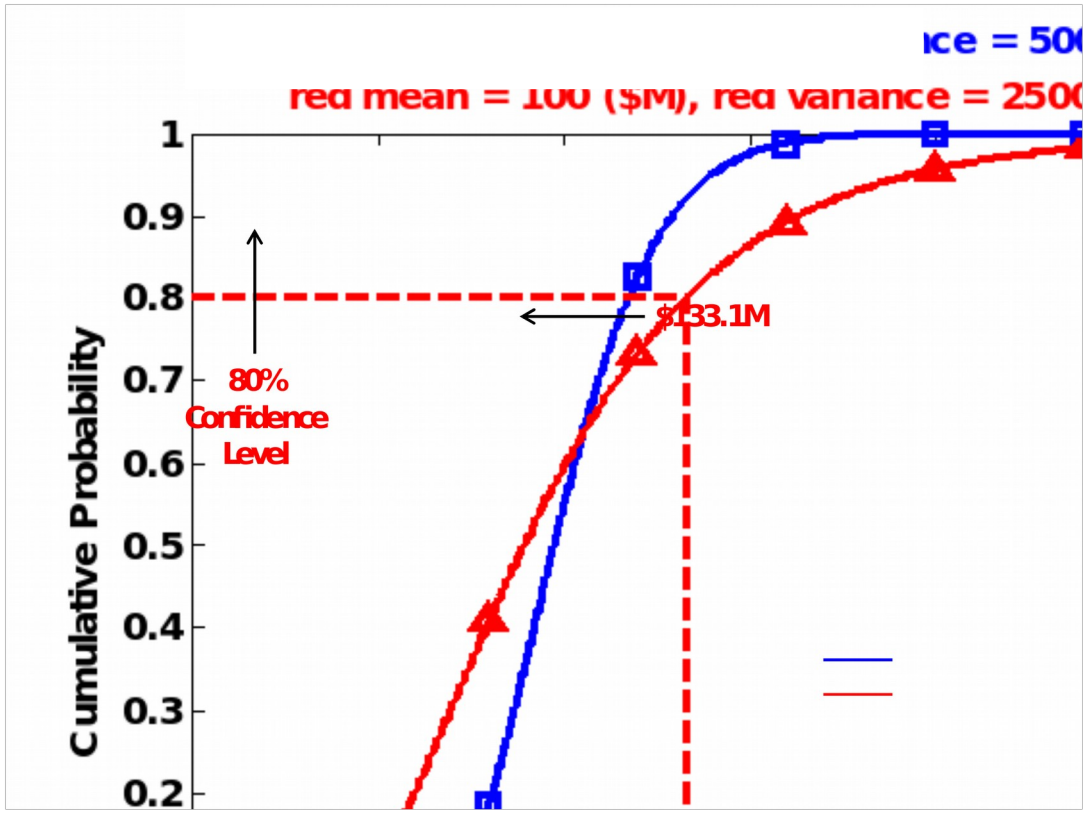
Incentive Fee Design
Notional Cost Estimates (PDFs)



- Lognormal cost estimates for two different programs with same expected cost, but different uncertainties:
  - Blue (lower risk effort…LRIP)
    - Mean = $100M
    - Variance = 500 ($M)^2
    - Standard Deviation = $22.4M
    - Coefficient of Variation = 0.22
  - Red (higher risk effort…EMD)
    - Mean = $100M
    - Variance = 2500 ($M)^2
    - Standard Deviation = $50M
    - Coefficient of Variation = 0.50

The red program has a greater chance of overrunning and underrunning Where there's risk, there's opportunity!

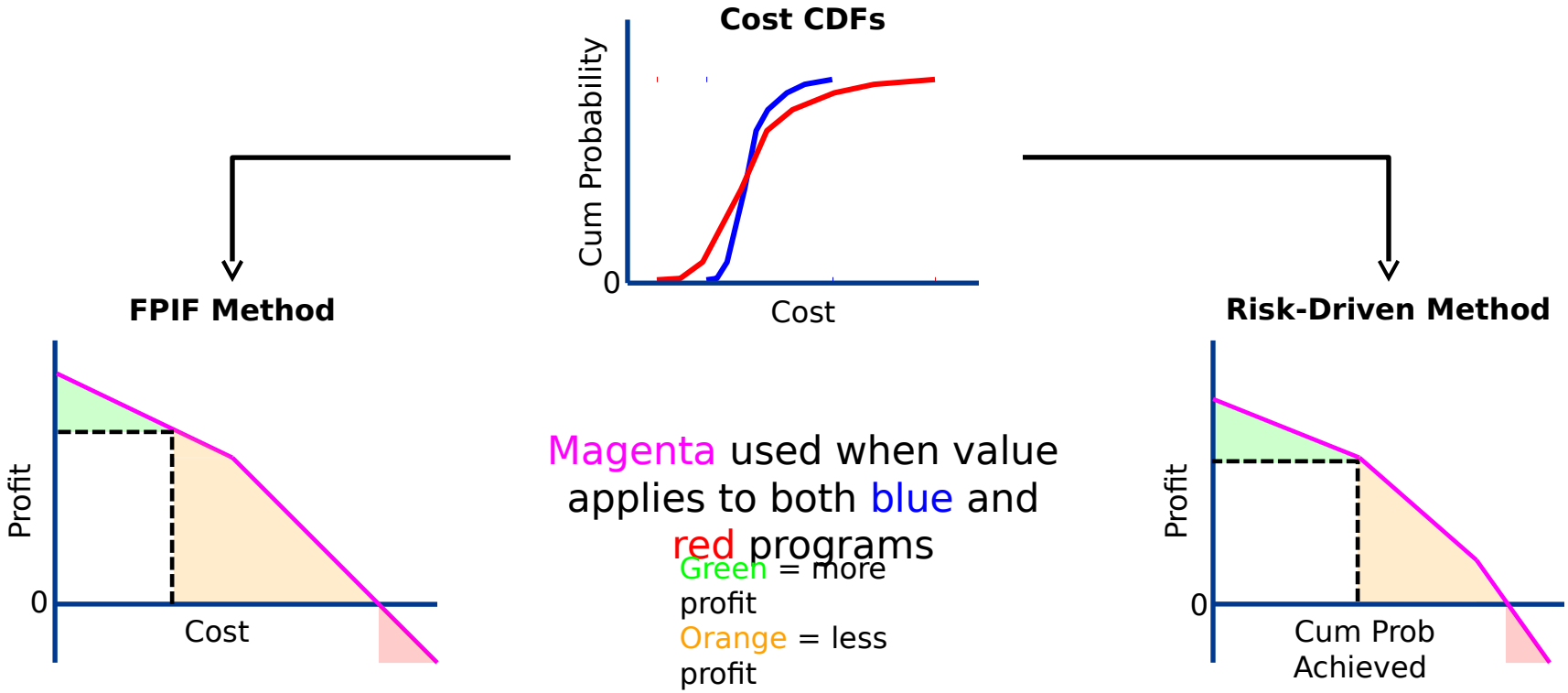
Incentive Fee Design
Notional Cost Estimates (CDFs)



Cost ($M)	Confidence	
	Blue	Red
65.0		25%
84.1	25%	
89.4		50%
97.6	50%	
100	54.4%	59.3%
117.5	80%	
120	82.5%	73.3%
133.1		80%
140.3	95%	
163.1	99%	
194.5		95%
268.4		99%

Each point on the CDFs represents the confidence level for an equal or lesser cost. For example, there's a 80% confidence the red program will be $133.1M or less

Incentive Fee Design



Magenta used when value applies to both blue and red programs

Green = more profit

Orange = less profit

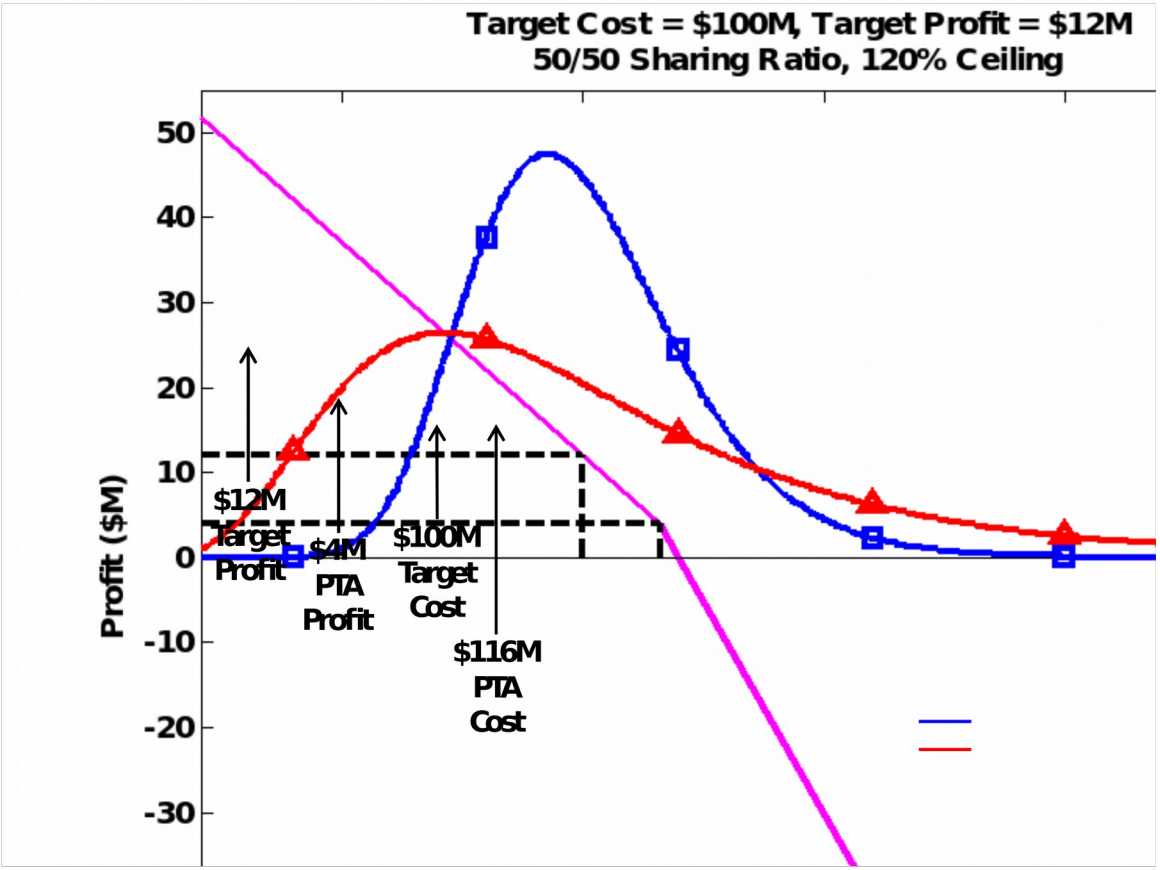
Red = loss

Risk-driven contract profit determined in the probability domain

Incentive Fee Design

FPIF Method

Cost Domain



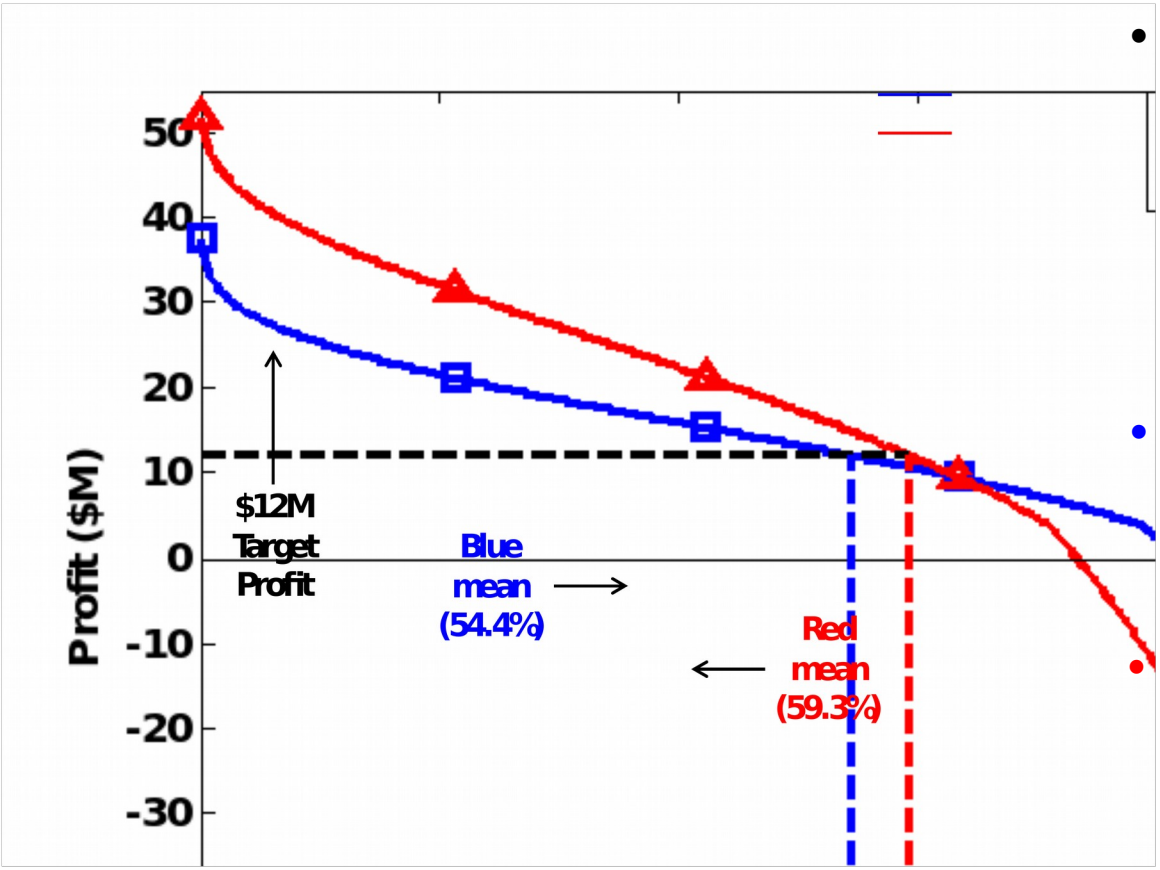
- Expected profit determined by multiplying the profit at each cost by its corresponding probability and then summing all possibilities
  - Blue expected profit = $10.9M
  - Red expected profit = $7.5M

Expected profits are different for blue and red programs
Confirms one size does not fit all

Incentive Fee Design

FPIF Method

Probability Domain



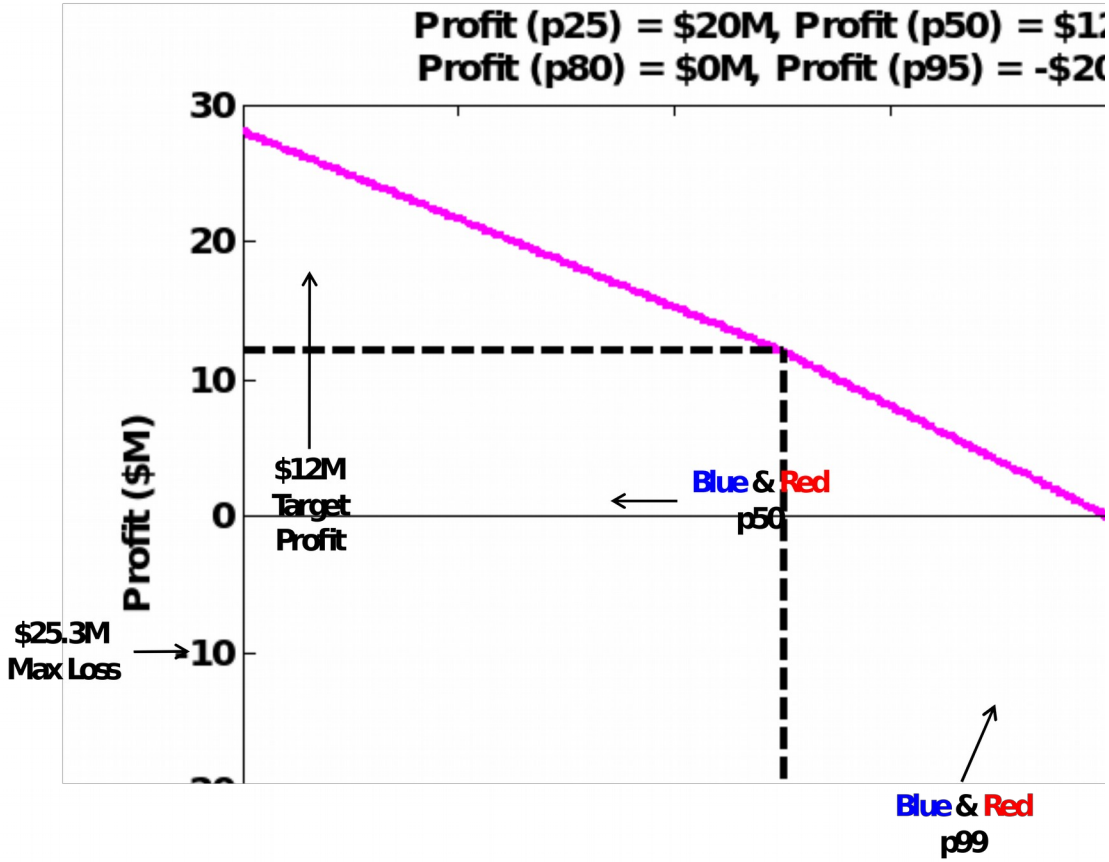
- Same contract, but x-axis changed to show profit earned as a function of cumulative probability achieved
  - For example, achieving the mean cost ($100M) on red program (p59.3) earns $12M
- Blue
  - Expected profit = $10.9M
  - Max loss = $43.1M
    - Cost (p99) – Cost (p82.5) = 43.1
- Red
  - Expected profit = $7.5M
  - Max loss = $148.4M
    - Cost (p99) – Cost (p73.3) = 148.4

This contract type clearly favors the blue cost estimate since the red max loss is not proportional to its expected profit[4,11]

Incentive Fee Design

Risk-Driven Method

Probability Domain



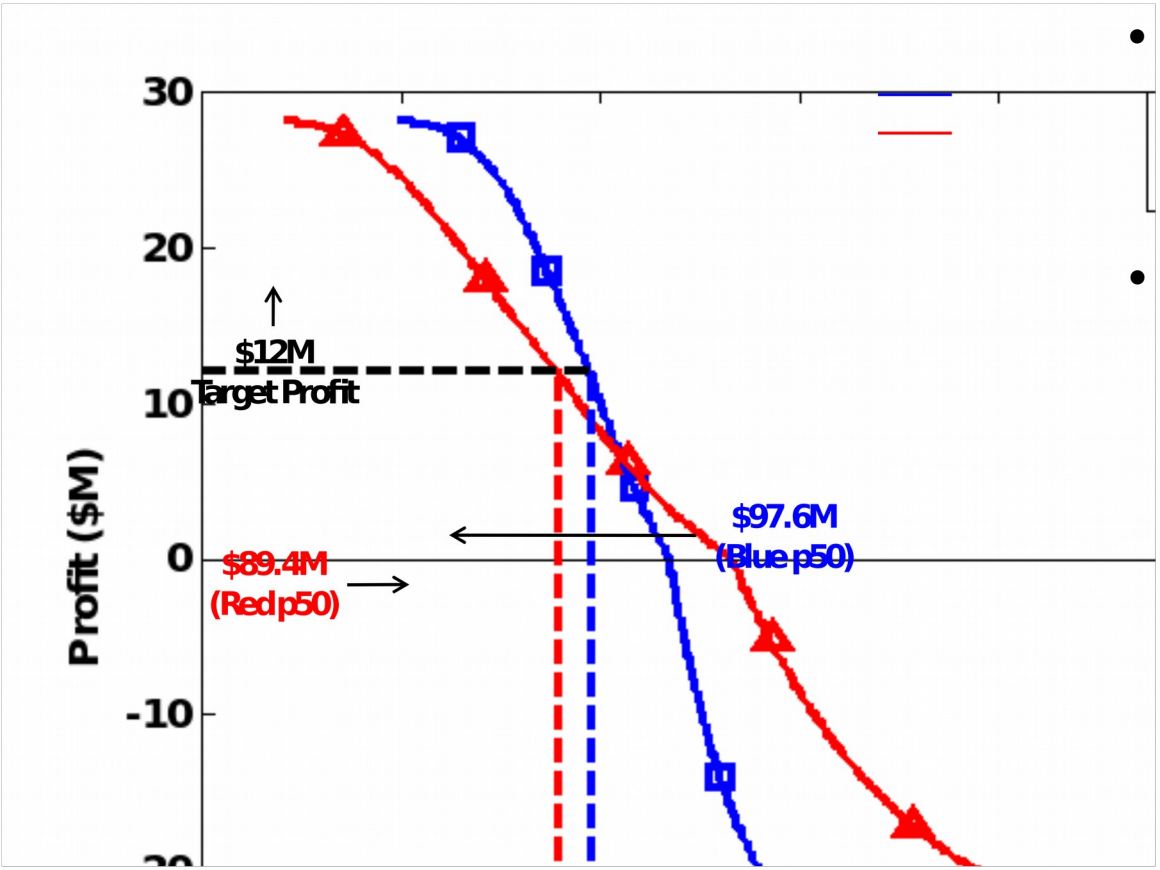
- Structured method to impose potential loss on contractors
- Blue & Red
  - Expected profit = $9.5M
  - Max loss (@ p99) = $25.3M
- Contractor earns equal profit for equivalent cost savings effort
  - For example, reducing cost from 50% to 45% confidence level earns same profit increase for blue and red programs

Now expected profits and max losses all match
Determining profits in probability domain normalizes cost estimate variances
Universal point of departure for system development programs?

Incentive Fee Design

Risk-Driven Method

Cost Domain



- Same contract, but x-axis changed to show profit earned as a function of incurred cost
- Government shares larger portion of red profit below target cost in return for limiting contractor's potential losses

Sharing curve flattens as cost uncertainty increases
Appropriate for government to share more risk for requiring more innovation

Outline

- Motivation
- Common Contract Types
- Incentive Fee Design
- Discussion
  - Benefits
  - Drawbacks
  - Limitations
- Summary

Discussion
Benefits

- Probabilistic cost proposals will give government more insight into contractor risk assessments
- More realistic cost estimates should lead to more predictable acquisition outcomes
  - Knowledge-based system development affordability assessments
  - If programs are still started, better chance they will be adequately funded
- Fewer cost overruns means less:
  - Funding instability
  - Cancelled programs (and lost investments)
  - Management casualties

Discussion
Drawbacks

- Government may have to allocate more funding to system development programs than usual (to cover wider range of possible costs)
  - Extra funding could be considered the usual cost of overruns
  - If required, could choose to terminate contract at p95 (or a little less); just make sure to keep significant loss potential
    - Reduces government's share from $243.1M to $174.5M
    - Reduces contractor's potential loss from $25.3M to $20.0M

Discussion
Limitations

- Risk-driven contracts do not directly address contract changes
  - However, with increased exposure to losses, contractors will likely:
    - Demand more clearly defined requirements and responsibly limit requirements creep
    - Augment precontract planning tasks
    - Propose more mature technologies
    - Recommend incremental or spiral development strategies
- If a change is necessary:
  - Consider applying the change to a separate CLIN (to maintain the integrity of the base contract incentive structure)
  - Consider using the same probabilistic sharing ratios as base contract (this could be prenegotiated)

Outline

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Summary

- Risk-driven contracts offer an alternative to traditional cost-plus contracts used for system development
  - Directly map probabilistic cost estimates to profit distributions
  - Offer structured method to impose chance of loss on contractors
  - Appropriately limit maximum losses for risky development efforts
- By properly aligning incentives with risk, risk-driven contracts should result in more realistic cost estimates
  - Reduces motivation for contractors to underbid competitions or acquiesce to government pressure to fit within expected budgets without trimming requirements
- Net outcome should be fewer overruns and greater acquisition predictability

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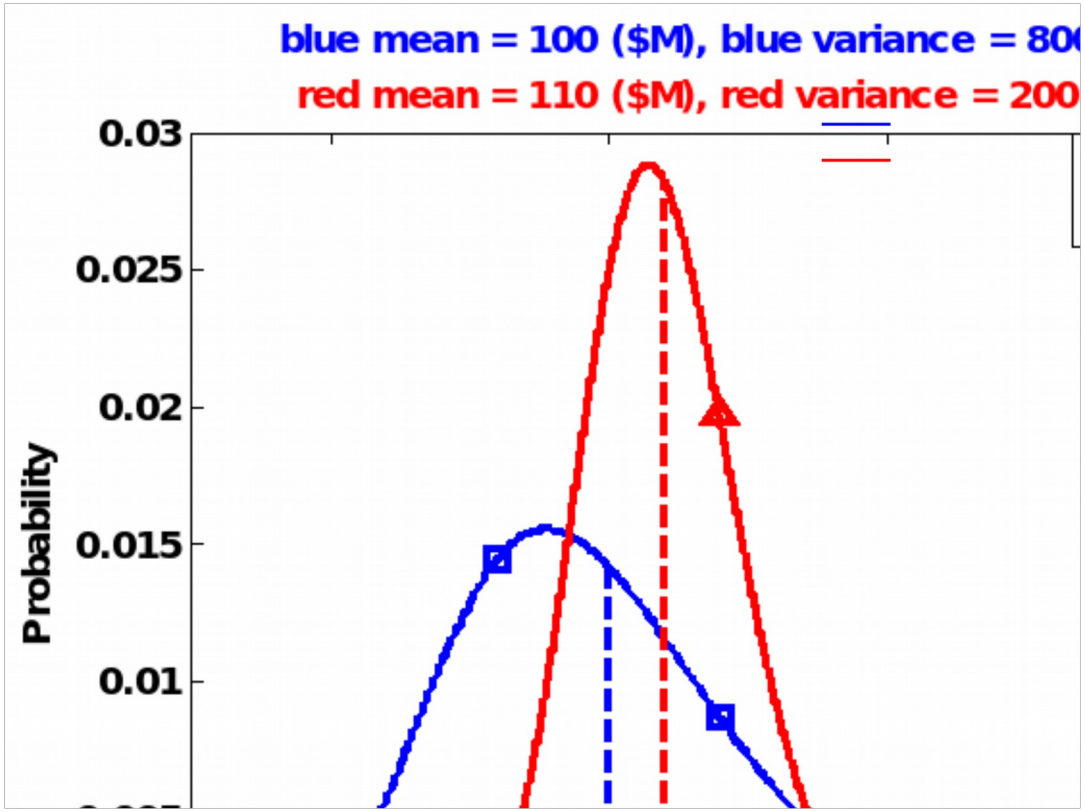
Backups

Vignettes
With Risk-Driven Contracts

- Purposely estimate low mean cost (to win competition and/or meet government affordability threshold)
  - Much higher chance of incurring substantial loss
- Purposely estimate high mean cost (to increase profit potential and reduce loss potential)
  - May lose competition and/or exceed government affordability threshold
- Purposely estimate large cost variance (to reduce loss potential)
  - Also reduces profit potential
  - May lose competition and/or exceed government affordability threshold
  - Government more likely to question cost realism
- Purposely estimate small cost variance (to increase profit potential)
  - Also increases loss potential
  - Government more likely to question cost realism

No easy way to game the system – Honesty is best policy!

Probabilistic Source Selection



- Need to require probabilistic cost estimate as part of cost proposal
  - Risk-neutral program office should select proposal with lowest expected cost (all other factors being equal)
  - Risk-averse program office should also consider variance of each cost proposal (all other factors being equal)

Calculating Profit

- Example incentive fee payment for blue program:
  - Final cost = $95M
  - Recall: m = $100M, v = 500 ($M)^2
  - Calculate μ and σ using these equations:
    - μ = 4.5808
    - σ = 0.2209

$$\mu = \ln\left(m^2 / \sqrt{v + m^2}\right)$$

$$\sigma = \sqrt{\ln\left(v / m^2 + 1\right)}$$

Note: ln() is the natural logarithm function

  - Determine cumulative probability achieved using Microsoft Excel
    - lognormdist (95, 4.5808, 0.2209) = 0.4515
  - Recall: Profit (p25) = $20M, Profit (p50) = $12M
  - Interpolate to determine final profit: $13,550,701.52

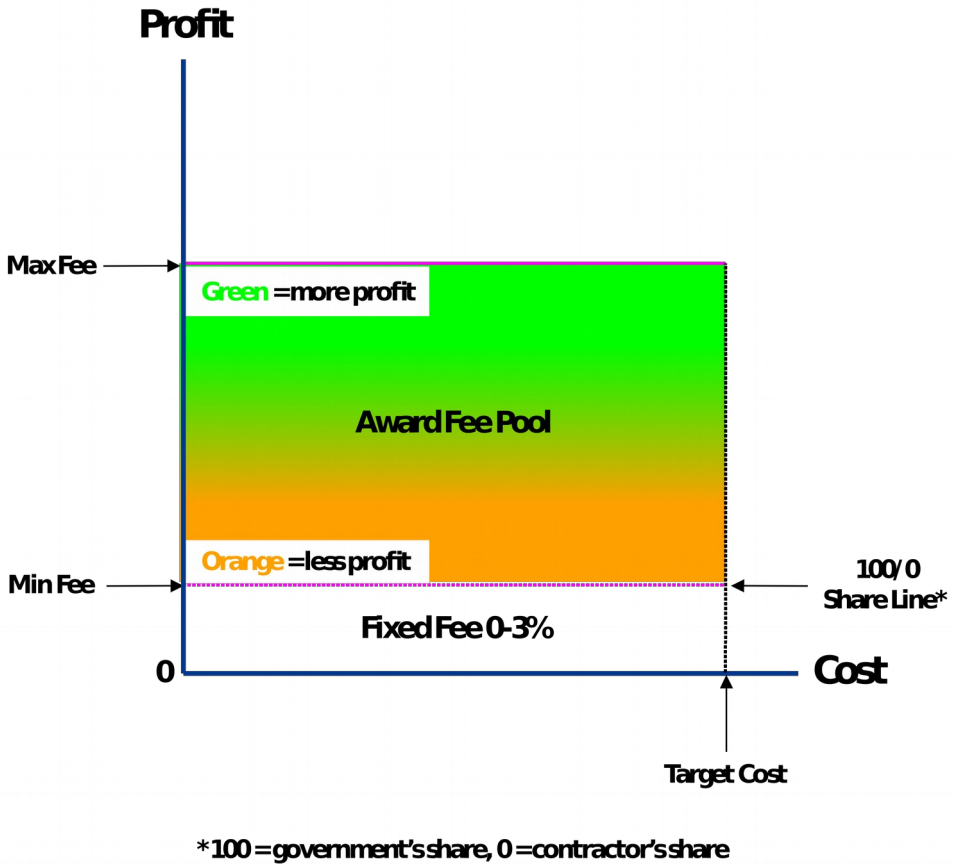
$$20 - \frac{(20 - 12)}{(0.25 - 0.50)}(0.25 - 0.4515)$$

- Consider using earned value estimate at completion (EAC) to calculate incremental incentive fee payments

Motivation
2010 QDR

Our system of defining requirements and developing capability too often encourages reliance on overly optimistic cost estimates. In order for the Pentagon to produce weapons systems efficiently, it is critical to have budget stability—but it is impossible to attain such stability in DoD's modernization budgets if we continue to underestimate the cost of such systems from the start. We must demand cost, schedule, and performance realism in our acquisition process, and hold industry and ourselves accountable. We must also ensure that only essential systems are procured, particularly in a resource-constrained environment. There are too many programs under way. We cannot afford everything we might desire; therefore, in the future, the Department must balance capability portfolios to better align with budget constraints and operational needs, based on priorities assigned to warfighter capabilities.

Common Contract Types
Cost Plus Award Fee (CPAF)

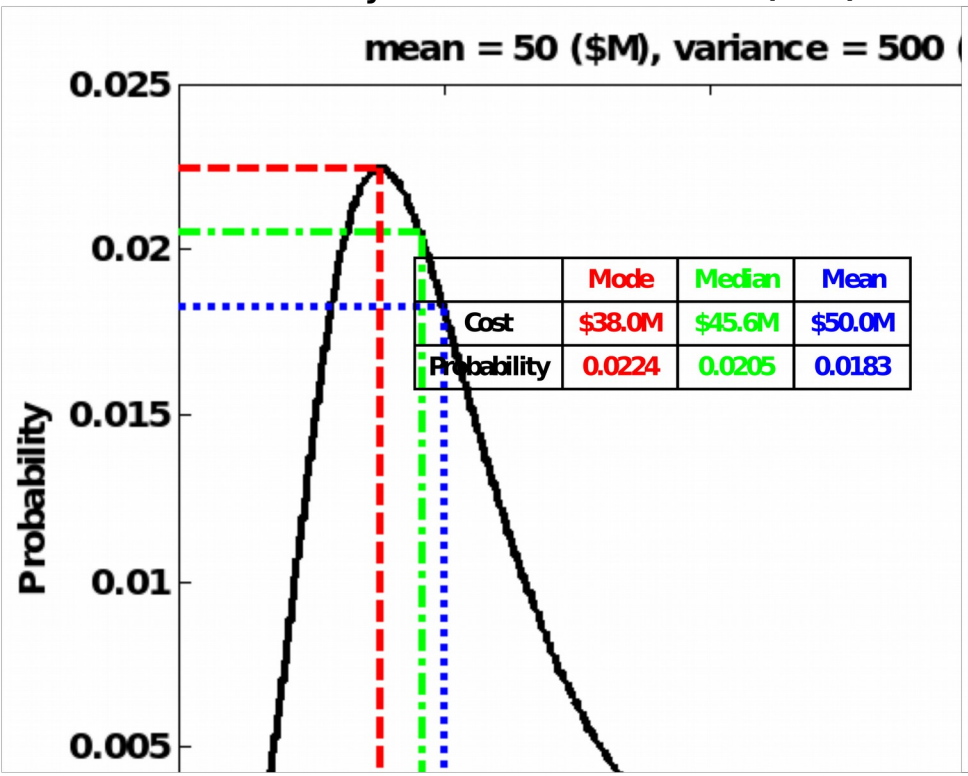


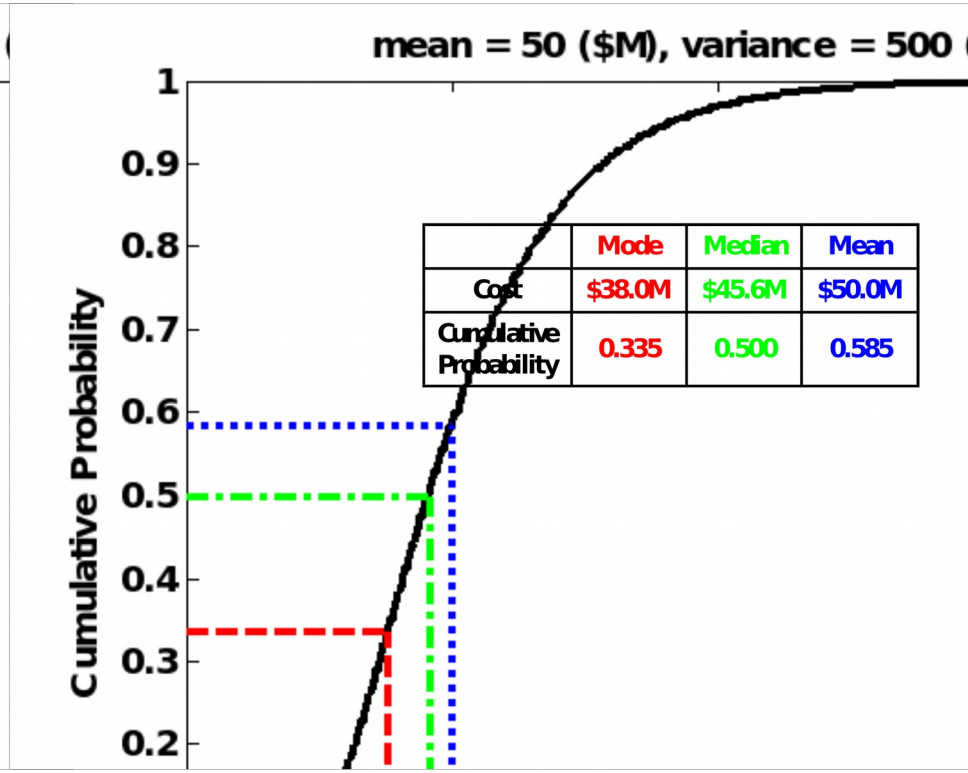
- Subjective, unilateral evaluation of contractor's performance based on award fee plan criteria
  - Allows consideration of "conditions under which [performance] was achieved" [FAR 16.401(e)(1)(ii)]
- "Suitable for use when the work to be performed is such that it is neither feasible nor effective to devise predetermined objective incentive targets applicable to cost, schedule, and technical performance" [FAR 16.401(e)(1)(i)]
- Periodic evaluations can lead to short-term optimizations
- Low ratings may cause tension
- Little incentive to control requirements creep since goal is to keep government happy
- Large administrative burden

Probabilistic Cost Estimation

- Lognormal Distribution Review
- Methods Overview
- Parametric Cost Estimation
- Engineering Buildup
- Expert Opinion Elicitation

Probabilistic Cost Estimation
Lognormal Distribution Review





- Lognormal PDF is skewed to the right
  - **Reflects disproportionate chance of an overrun**[11]
- Mode = single most probable value, peak of PDF
- Median = 50th percentile: 50% values lower, 50% values higher
- Mean = expected value; average of all possible

Probabilistic Cost Estimation
Methods Overview

- Two basic methods to estimate cost uncertainty:[12]
  - Parametric based on Cost Estimating Relationships (CERs)
  - Engineering Buildup based on Work Breakdown Structure (WBS) elements
  - Not mutually exclusive; can be used together when appropriate
- Both require expert opinion elicitation for inputs
- Both should be sanity checked against similar past projects (analogy method)
- Both should also consider the Scenario-Based Method (SBM) to consider other possible risks[13]
- Both produce a PDF and CDF that quantifies the expected value and variance

Probabilistic Cost Estimation
Parametric Cost Estimation

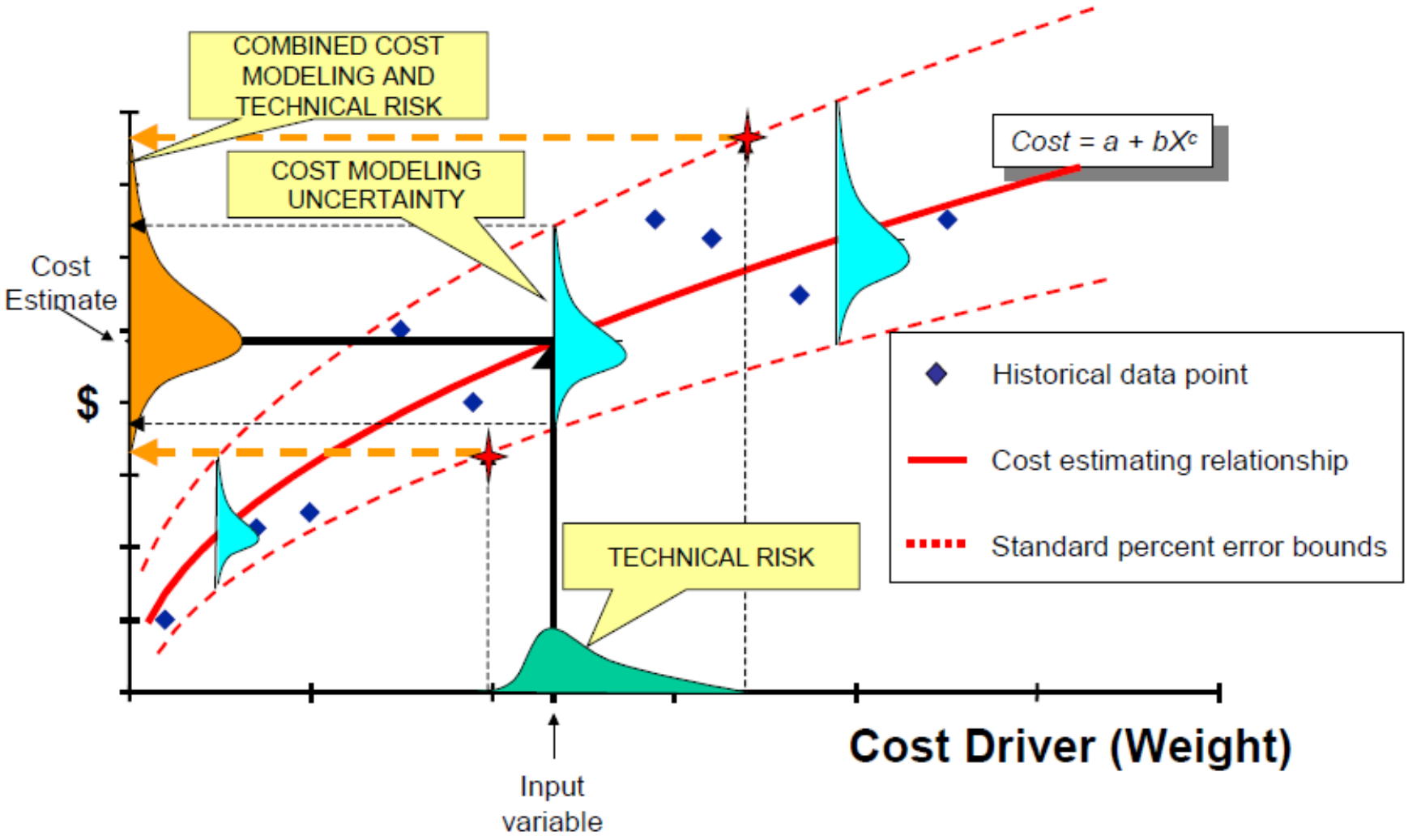
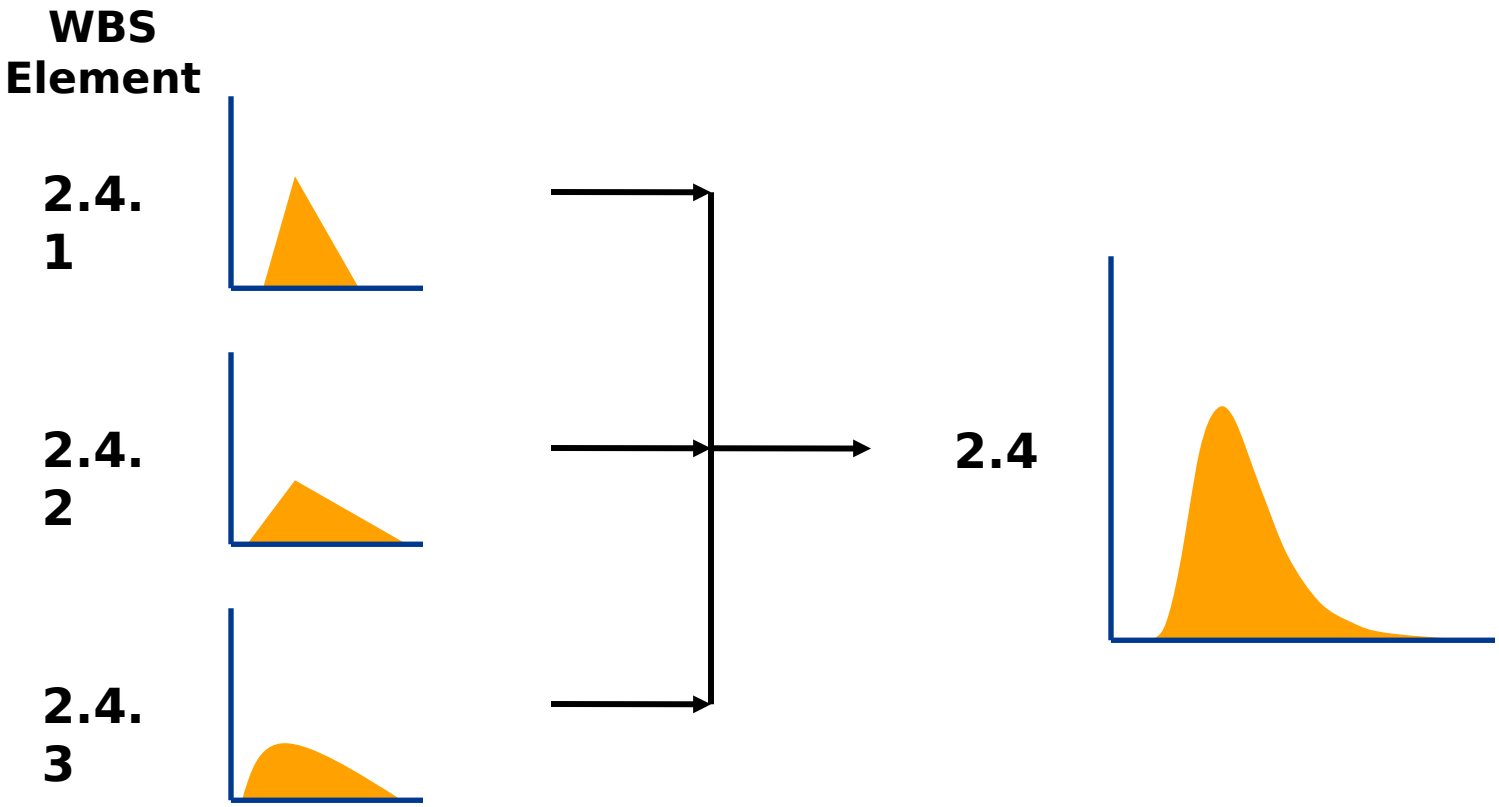


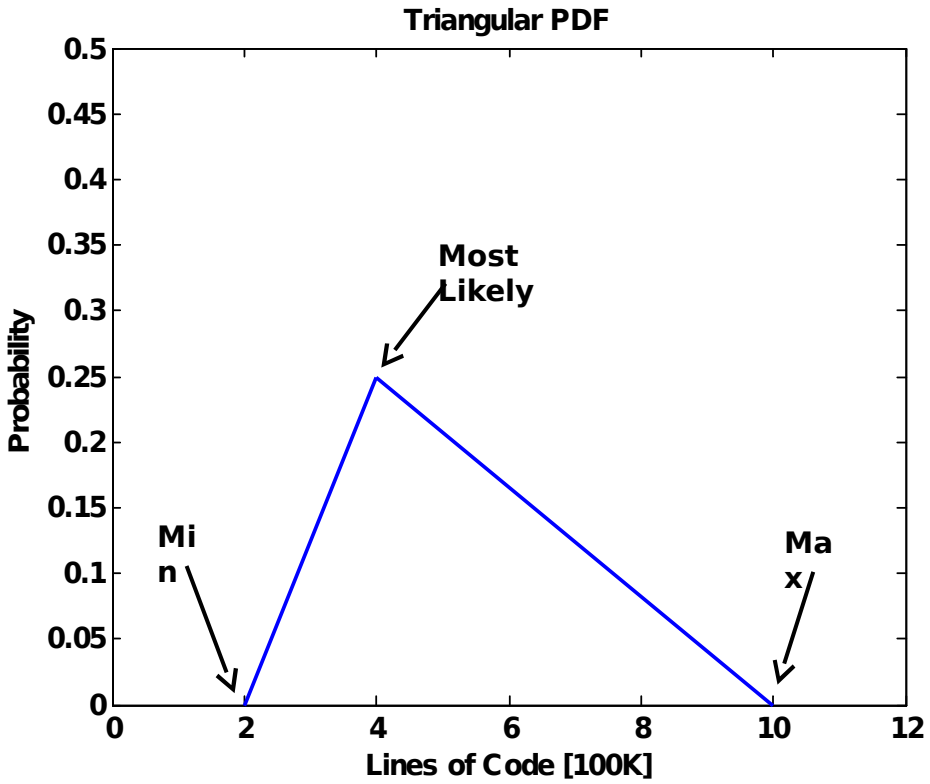
Figure copied from SSCAG Space Systems Cost Risk Handbook, 16 November 2005.

Probabilistic Cost Estimation
Engineering Buildup



Resultant PDF based on Monte Carlo draw from each WBS element PDF
Care must be taken to properly handle correlation between

Probabilistic Cost Estimation
Expert Opinion Elicitation



- Simplified example for software lines of code
- Experts asked to quantify min, max, and most likely estimates based on their experience
- Triangular PDF is easily generated
- Extensive literature available on best elicitation methods[13]
  - Most likely estimate usually overly optimistic
  - Max usually not worst case